TEMPORARY THRESHOLD SHIFT
AND THE TIME PATTERN OF NOISE EXPOSURE*

Raymond Hétu, Ecole d'orthophonie et d'audiologie, Université de Montréal, C.P. 6128, Montréal, Québec, H3C 3J7.

ABSTRACT

Temporary threshold shift (TTS) is related to the time pattern of noise exposure in a relatively complex fashion. This relationship essentially involves the on-fraction, the period of intermittence and the sound level during noise bursts and quiet intervals. Data from recent studies on the influence of these exposure parameters and more specifically of their mutual interaction is reviewed. Unpublished data is presented on the effect of the interaction between the on-fraction and the period of intermittence on the growth of TTS and also on the effect of the ambient sound level on the recovery from TTS. The predictability of TTS is examined in the context of both laboratory and real life conditions. The implication for the recommended exchange rate between sound level and time in occupational noise exposure limits and for administrative control of exposure is discussed.

SOMMAIRE

Le découpage temporel de l'exposition à un bruit intense joue un rôle important dans l'acquisition et la récupération de la fatigue auditive (DTS: décalage temporaire des seuils d'audition). Les facteurs en cause sont la fraction temporelle, la période d'intermittence, le niveau sonore qui prévaut durant les expositions et les pauses. Un examen critique des données scientifiques disponibles de même que la présentation de données originales ont permis de définir les limites dans lesquelles on peut prédire le DTS dans des conditions d'exposition en laboratoire et en usines bruyantes. De cette analyse ont été tirées des implications à l'égard de l'adoption d'un coefficient de pondération durée-intensité dans le contexte des limites d'exposition au bruit en milieu de travail.

Introduction

Noise-induced temporary threshold shift (TTS), sometimes called auditory fatigue, is a reversible loss of hearing sensitivity following exposure to high sound levels. This phenomenon has been studied extensively under laboratory conditions as a possible predictor of occupational hearing loss (also termed "noise-induced permanent threshold shift", PTS) for a variety of noise exposure conditions. During the last 25 years, a fairly large number of experimental studies have been conducted on the influence of the time pattern of noise exposure on growth and recovery of TTS. They all had a common justification, that is to contribute to the identification of hearing damage risk criteria for intermittent exposure to industrial noise. This contribution was further emphasized by the scarcity of reliable data on occupational hearing loss following intermittent and variable noise exposures (Radcliffe, 1970). Because these studies shared a common aim of predicting TTS in real life situations (and from that point, the possible growth of permanent threshold shift-PTS), they are reviewed in this specific context.

The rationale of the present analysis is that, apart from considering the possibility of predicting PTS from TTS, one must establish how TTS can <u>actually</u> be predicted

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for a number of real life conditions for which it is specifically set forth as a guideline for limiting noise exposure.

The variables that are involved in predicting TTS from intermittent exposures are the on-fraction, the period of intermittence, the sound level during noise bursts <u>and</u> during quiet intervals and finally the total time of exposure. Their respective influence and their possible mutual interactions will be briefly examined and implications on different exchange rates between sound level and time will be considered.

1. The influence of the on-fraction:

Because of the lack of a simple model relating the variables just mentioned, the influence of the exposure pattern on TTS is usually described essentially in terms of the on-fraction rule (Burns, 1969, 1973; Kryter et al., 1966; Melnick, 1978, 1979; Sulkowski, 1980; Ward, 1963, 1973). This rule states that TTS from intermittent noise is less than if the exposure is continuous. The reduction in the amount of TTS_2 (TTS_2: TTS measured 2 min after the end of exposure) is proportional to the ratio of the time notoccupied by noise to the total time of exposure (Ward et al., 1958). This was said to hold for burst durations between 250 msec and 2 min and for sound energy above 1000 Hz.

Evidence show that, for a constant total amount of sound energy, the magnitude of TTS is smaller as the on-fraction is decreased. This is exemplified by the data presented in Figure 1. These are results from an experiment conducted in our laboratory: 8 normal hearing subjects were exposed to a pink noise during 128 minutes; the on-off period was equal to 1 min, the on-fractions (R) were 0.1, 0.5, 0.9 and 1 and the corresponding sound pressure levels (L_{pA}) were 106, 99, 96.5 and 96 dBA respectively. These L_{pA} were selected in order to obtain a constant total amount of energy across the 4 noise conditions, the sum of energy being equivalent to 90 dBA for an 8 hour exposure.

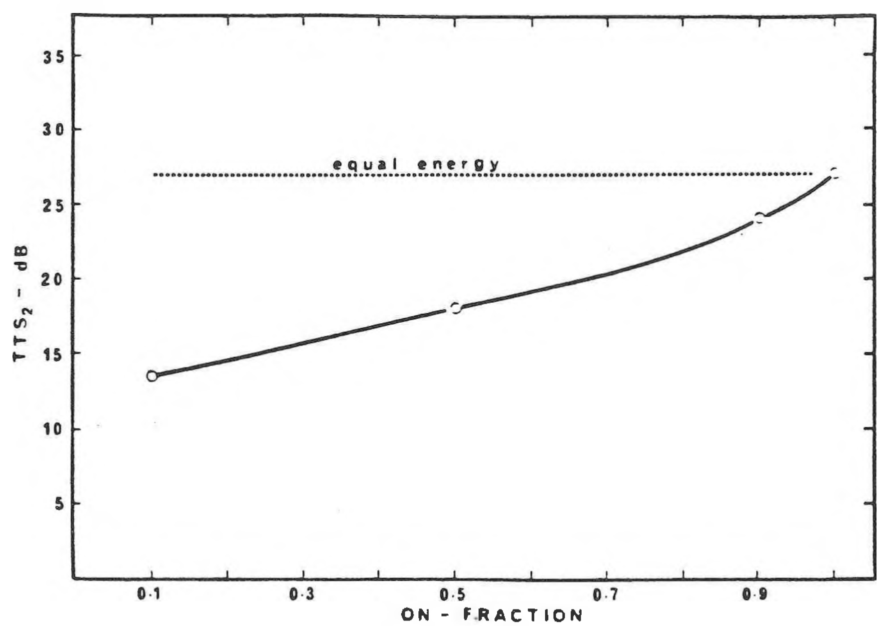

Fig. 1. TTS_2 at 4 kHz as a function of the on-fraction for a constant cumulated sound energy equivalent to 90 dBA for 8 hours; period of intermittence = 1 min; total exposure duration = 128 min (N = 8)

It follows clearly fron the results presented in Figure 1, as well as from those from other studies (Ward, 1976, 1981) that, for a constant final TTS_2 at 4 kHz, the exchange rate between sound level and exposure time varies inversely with the on-fraction, provided that the period of intermittence is in the range of one or two minutes.

But despite a relatively great care of all reviewers in stating the limits of the on-fraction rule (see Ward, 1963, 1973; Burns, 1969, 1973; Melnick, 1978, 1979), its interaction with other exposure variables is rather neglected, possibly because of the lack of parametric studies on these interactions. Nevertheless, some indications are provided by the presently available data as shown in Figure 2. The on-off period, the sound level and the frequency characteristics of the noises studied are identified at the bottom of this figure. All data were obrained after 8-hour exposures, except for line A for which it was 1.7 hour. It is worth mentioning that the data points connected by line A were part of the original data set that served as the actual basis for the on-fraction rule.

When comparing the slope of the different lines in this figure, one can see that TTS_2 is certainly not a simple function of the on-fraction of the noise. The relationship between TTS_2 and the on-fraction appears to change

- with the sound level: comparing line B to C and also line D to line E shows that, for similar on-off periods, different sound levels are associated with different slopes.
- with the period of intermittence: comparing line B to line D for identical sound levels.
- possibly with the total exposure time: as one compares line A, fitting data for 1.7-hour exposures with line E, describing results for 8-hour exposures; but, here, the comparison is further complicated with a variation in the period.

With all these interactions, is it still appropriate to describe the influence of the exposure pattern strictly or mainly in terms of the on-fraction rule?

2. The influence of the period of intermittence:

The influence of the period of intermittence alone can be described by the results from 4 different parametric studies, as shown in Figure 3. Line A refers to 8-hour exposures to an octave-band level of 85 dB and line B to 95 dB. Line C corresponds to data for 2-hour exposures to a broadband noise at a sound pressure level of 101 dB. Line D refers to TTS_2 from an octave band level of 112 dB during 52 min. It must be emphasized that all studies bear strictly on exposure involving an on-fraction of 0.5 (exactly 0.46 in the case of line D).

Generally speaking, the amount of TTS_2 is exponentially related to the period of intermittence. For each doubling of the period, a 1.5 to 2 decibels increase in TTS_2 is observed. But, this does not seem to hold for very short periods and very high sound levels (line D). Besides, it is not clear whether differences in the slopes of the lines relating TTS_2 to the logarithm of the period merely reflect sampling errors or interactions with the sound level or other variables.

Moreover, the period can dramatically influence the pattern of recovery from TTS, if one recalls the results reported by Ward (1970, fig. 5); cycles of exposure and quiet of 10-sec duration, producing relatively small amounts of TTS_2, required more than 2 days for complete recovery in a number of subjects. It is surprising that this observation did not give rise to more research on the exact exposure parameters that were responsible for such an effect. Finally, the effect of periods longer than 40 min have not been studied as such. For what length of the period does an intermittent exposure produce the same amount of TTS_2 as a continuous exposure of equal cumulated energy and total exposure time is still an open question.

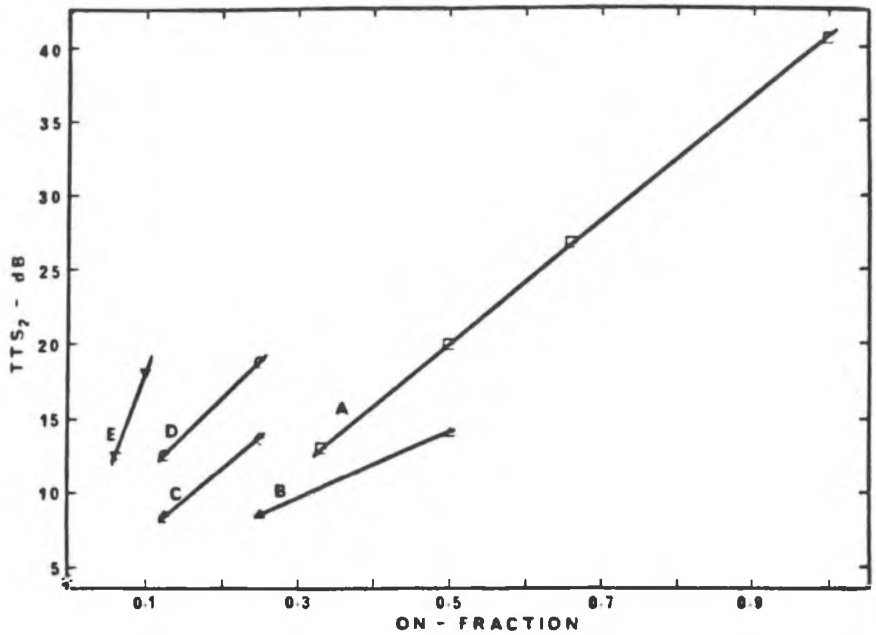

Fig. 2. TTS_2 at 4 kHz as a function of the on-fraction
Line A: 1-1.5 min on-off, 106 dB, pink noise (Ward et al., 1958)
Line B: 1.5 min on-off, 90 dB, 2800-5600 Hz (Ward, 1976)
Line C: 1.5 min on-off, 95 dB, 2800-5600 Hz (Ward, 1976)
Line D: 40 min on-off, 90 dB, 2800-5600 Hz (Ward, 1976)
Line E: 50 min on-off, 105 dB, 1400-2000 Hz (Ward, 1970)

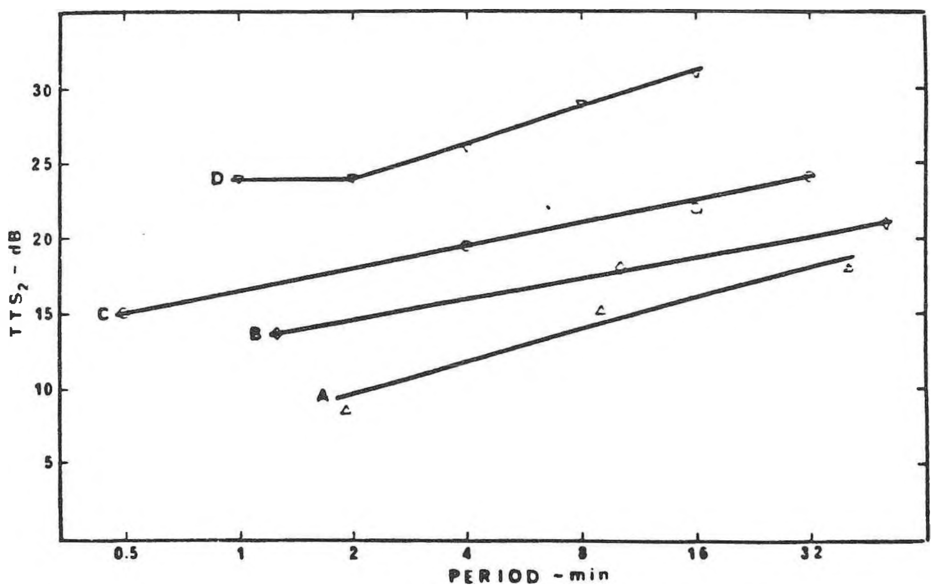

Fig. 3. TTS_2 at 4 kHz as a function of the period of intermittence
Line A: Duration - 480 min, 85 dB, 1200-2400 Hz (Ward, 1976)
Line B: Duration - 480 min, 95 dB, 1400-2000 Hz (Ward, 1970)
Line C: Duration - 128 min, 101 dB, pink noise (Hétu & Trémolières, 1977)
Line D: Duration - 52 min, 112 dB, 1700-3400 Hz (Selters & Ward, 1962)

3. The influence of the sound level during the so-called quiet intervals

Recovery from TTS has generally been assumed to take place at an optimal rate when the noise level falls below the critical level for the growth of TTS. This level, defined as "effective quiet" was first estimated to be 85 dB SPL for a broadband noise (Ward et al., 1958) and between 65 and 75 dB for the octave bands for which the ear is more sensitive (Ward et al., 1959). Surprisingly, octave band levels between 85 and 89 dB were adopted in the CHABA criteria (Kryter et al., 1966) and the Intersociety Committee (Radcliffe, 1970) defined "no noise" as levels below 90 dBA.

A number of studies has been performed since that time, using essentially two kinds of procedures: (a) measures of the influence of the sound level during the quiet intervals of an intermittent exposure and (b) measures of the rate of recovery from a given TTS_2 as a function of the ambient continuous sound level.

Results from the studies belonging to the first group (i.e.: intermittent exposures) clearly showed that broadband noise levels near or above 70 dBA during "quiet" intervals did increase the final amount of TTS_2 (Klosterkötter et al., 1970; Schmideck, Henderson & Margolis, 1972, 1975). Results from the other group of studies performed by Austrian researchers (Lehnhardt and Bucking, 1968; Schwetz et al., 1970; Dopler et al., 1973) indicate that recovery from TTS is actually slower in a 70 dB SPL broadband noise than in a quieter condition. No such difference was observed in a 65 dB octave band level centered at 2000 Hz.

In a recent study, Ward, Cushing and Burns (1976) by combining the two procedures mentioned above (using an intermittency period of 1.5 min and a post-exposure period of 2 hours) obtained octave band levels of effective quiet that were similar to those estimated for the most sensitive frequencies in the study performed in 1959 (see: Ward et al., 1959), these levels falling between 65 and 75 dB per octave.

In our laboratory, we have studied the influence of the level of a continuous broadband noise on the recovery from TTS with 2 groups of 12 subjects.

When comparing, in a first series of experiment (Figure 4 A) the effect of a 75 dBA to a 40 dBA recovery condition, significant differences ($P < 0.01$ - Wilcoxon) were obtained between the two conditions after 120 min of exposure. In a second series of experiments, four recovery conditions were compared (50, 60, 70 and 80 dBA), as shown in Figure 4 B. At 50 dBA, a significant recovery ($P < 0.006$ - Friedman X^2), was obtained between the 60th and the 120th minute of exposure, while no such difference could be observed at 60 and 70 dBA. A significant increase in TTS was obtained at 80 dBA for the same period. Thus, in both series of experiments, difference between conditions essentially occured during the second hour in the recovery environment.

These results, as well as those from the studies mentioned earlier, clearly imply that the definitions of effective quiet or "no noise" in damage risk criteria based on TTS (i.e.: the CHABA and the Intersociety Committee proposals) as well as in the most recent formulation of the OSHA standard (OSHA, 1981) do not correspond to conditions of optimal recovery from TTS. It also implies that the prediction of the growth and the recovery of TTS under intermittent exposure must take into account the effect of the actual sound level associated with what is considered as a quiet interval, if such a prediction intends to apply to real life situations.

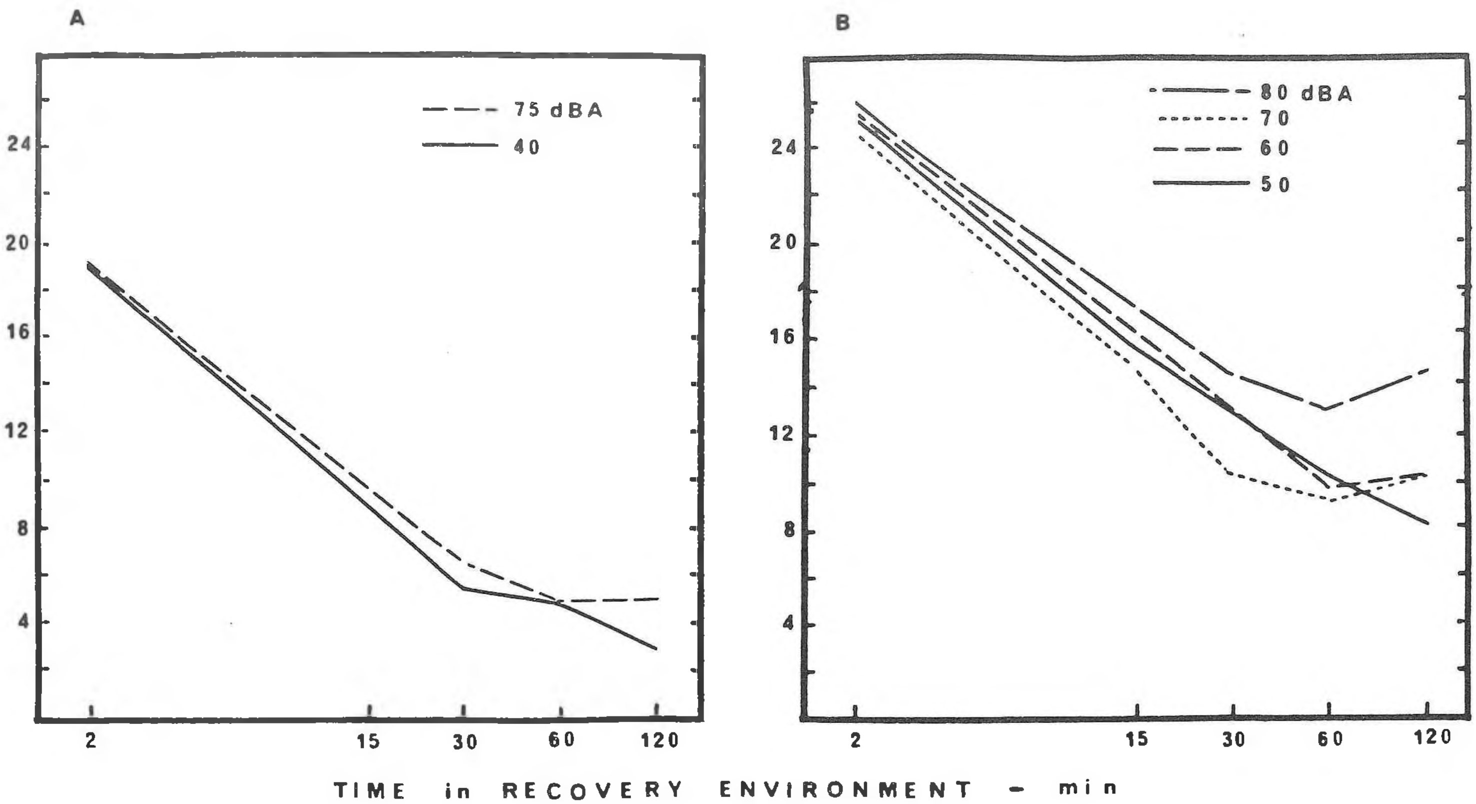

Fig. 4. Recovery from TTS at 4 kHz as a function of the ambiant sound level (parameter) in two separate experiments A and B, each involving 12 subjects.

4. Implications for a generalized time-intensity trade-off for various exposure patterns

The majority of present North America legislations concerning noise exposure limits and PTS rely on a 5-dBA time-intensity trading relationship. This was based on a simplification of criteria derived from TTS studies on intermittent exposures, although the link between TTS and PTS is notwell established. As shown in Figure 1, such a trade-off is certainly conservative if the on-fraction is smaller or equal to 0.5 together with a on-off period of 2-3 minutes and with a sound level below 65 dBA during quiet intervals.

Now, the question is: does such a condition ever occurs in industry? Few representative statistics on the exposure patterns for typical noisy jobsites are presently available; studies on the industrial noise environments have been more frequently concerned with the spectral characteristics of the noise (see: Royster and Stephensen, 1976; Bostford, 1967). Experience show however:
- that the actual quiet intervals (rest periods) are very short as compared to the length of the exposures to high sound levels
- that the rest periods are not frequent in a normal workday
- and that they are frequently characterized by sound levels clearly above 65, even above 75 dBA.

In other words, the on-fractions are larger than 0.5, the intermittency periods longer than a few minutes and the time intervals of low noise levels do not represent effective quiet conditions. The effects of these exposures are more probably nearer those from varying noise conditions or continuous exposures of less than 8 hours than those from intermittent noise.

In this context, a uniform time-intensity trade-off of 5 dBA is certainly inappropriate, more especially as the original CHABA proposal comprised a 2 dB sound level increase for reducing the duration of exposure from 8 to 4 hours and a 3 dB increase for a decrease in exposure time from 4 to 2 hours or from 2 to 1 hour.

The situation is even more paradoxical when one considers that the 5-dBA trade-off is used to set limits of daily exposures which last more than 8 hours (see: OSHA, 1981). Again, to my knowledge, no statistics on overtime and on compressed workweek schedules are presently available. But, overtime is not an unlikely event in a number of jobsites for a majority of noisy plants. The 5-dBA trade-off was based on the fact that for an equal amount of energy, TTS was smaller when the exposure was intermittent. Now it is used to define permissible exposures that produce asymptotic threshold shifts (ATS; see: Melnik, 1976; Nixon et al., 1977). Recovery from ATS generally requires more than 16 hours (Mills et al., 1970; Mosko et al., 1970) while the rest period between two days work in this condition is smaller than 16 hours. One would have expected that ATS data would have justified exposure limits for durations longer than 8 hours that were more conservative.

5. Conclusion

A fairly large number of studies have been conducted on the influence of the time pattern of noise exposure on TTS. The amount of data presently available allows one to predict the growth and the recovery of TTS for a number of laboratory conditions. The use of exponential models for predicting TTS has been shown by Keeler (1976) to be highly accurate for a variety of exposure patterns. However, these models need to take into account the influence of the exact sound level during the so-called quiet intervals as well as the interaction between the on-fraction and the intermittency period, in order to state valid predictions for a majority of real life situations. More data are needed to clarify the exact contribution of the on-fraction for extreme values of the period length, that is a few seconds and an hour or so.

Looking back to the way TTS studies were used to set guidelines for industrial noise exposure control (i.e.: The Intersociety Committee proposal, see: Radcliffe, 1970) provides a good example of oversimplification and premature generalization of empirical rules bases on a limited number of laboratory observations. Studies of the actual exposure patterns in noisy industry are seriously needed before claiming being able to predict the growth and the recovery of TTS in these particular conditions. Whatever may be the predictive value of TTS for the growth of PTS, there is a need to know how the auditory perception of millions of industrial workers is subject daily to serious disturbances because of occupational noise exposure.

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